

## **Autonomous Target Tracking for Asteroid Landing**

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### **ABSTRACT**

Asteroid landing of spacecraft using autonomous target tracking based on passive electro-optical sensing information is presented. The Gabor filters are used for the recognition and tracking of planetary features. A new guidance and navigation method based on matching image features based on stereo cameras is proposed. Simulation testing has been conducted to verify the passive guidance approach.

### **1. INTRODUCTION**

Future missions to explore small bodies (e.g., asteroids and comets) will emphasize small, low cost spacecraft with autonomous landing capability. Due to the uncertainty of asteroid surfaces and communication delays, traditional remote guidance and control from earth is impractical and ineffective. Onboard, autonomous target tracking during descent operations will be required to land the spacecraft at the desired safe spot using target-relative guidance information.

One of the key research areas in autonomous spacecraft landing technology is the development of relative ranging [1]-[2]. Laser ranging is ideal for measuring the relative range between the spacecraft and desired landing spot, but a laser-ranging device is an active sensor and consumes a lot of power, it is not

suitable for small spacecraft and deep space exploration. However, recent advancements in image processing and computer vision algorithms [3]-[7] have provided us with an opportunity to apply passive stereo cameras to establish the relative range during spacecraft landing. With the enhancement of microprocessor technology, a passive electro-optical guidance algorithm [8]-[9] can be implemented in real time, thus providing a low-power, low-cost solution to the ranging problem.

For lateral guidance and maneuvering, we propose a feature based passive ranging and guidance method that extracts object features from the images captured by down-looking stereo cameras. The Gabor filters [10] are employed for the recognition and tracking of planetary features. Previous applications of the Gabor filters [4] to planetary images were for the purpose of pointing scientific instruments autonomously at interesting features during flybys. In this paper, we focussed the efforts on tracking planetary features during landing operations. Simulation testing has been conducted to verify the passive guidance approach.

## 2. FEATURE DETECTION USING THE GABOR FILTERS

The Gabor filters are used to detect planetary features and guide the spacecraft to land on a desired spot. The Gabor filter output can be constructed as follows:

$$C(x, y) = \max_{\theta} \|I(x, y) \otimes \Phi_j(x, y, \theta) - s_j / s_k I(x, y) \otimes \Phi_k(x, y, \theta)\|$$

where  $k=11$ ,  $j=10$ ,  $s_j=2^{j/2}$  (scale factor),  $I(x, y)$  is the original image

$$\Phi_j(x, y, \theta) = \Phi(s_j x, s_j y, \theta)$$

$$\Phi(x, y, \theta) = e^{-(x'^2 + y'^2) + i\pi x'}$$

$$x' = x \cos \theta + y \sin \theta$$

$$y' = -x \sin \theta + y \cos \theta$$

$$\theta = 0, 90, 180 \text{ and } 270 \text{ degrees (Orientation)}$$

Different asteroid images from the Near Earth Asteroid Rendezvous (NEAR) mission [11] are tested. The results show that the Gabor filtering approach can detect planetary features efficiently, as shown in Figures 1-4. Because the Gabor filter output is able to consistently detect fiducial features in the images, further testing is performed to evaluate its potential application in processing stereo images and matching features on both images.

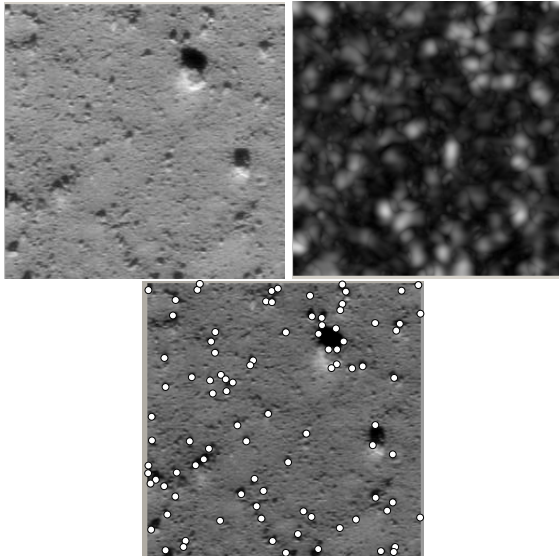


Figure 1. Gabor filter result 1 (Top: original image and Gabor filter output, Bottom: detected features).

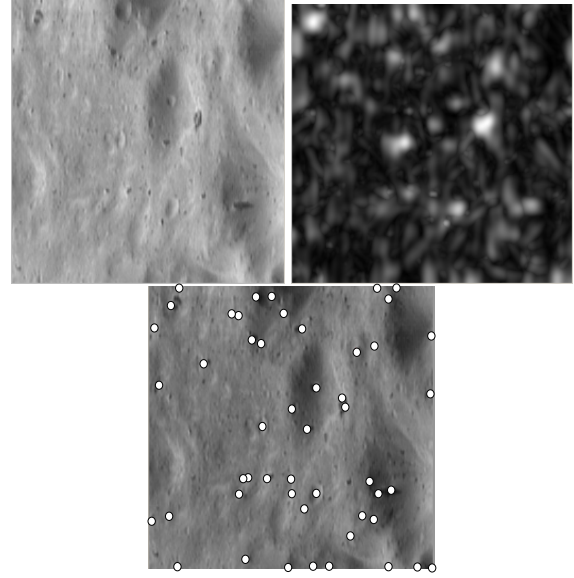


Figure 2. Gabor filter result 2 (Top: original image and Gabor filter output, Bottom: detected features).

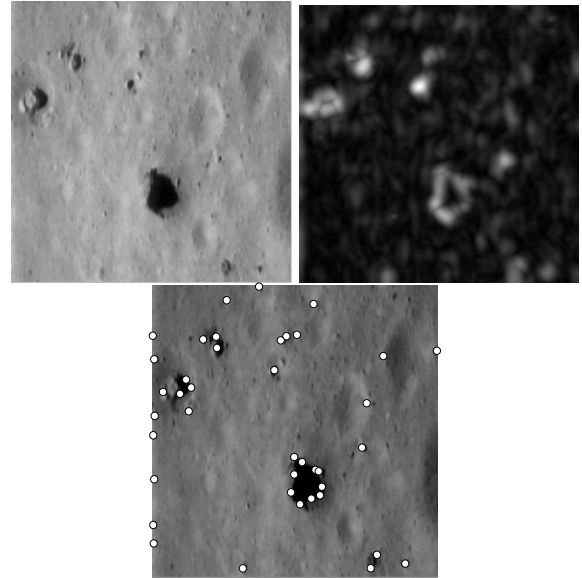


Figure 3. Gabor filter result 3 (Top: original image and Gabor filter output, Bottom: detected features).

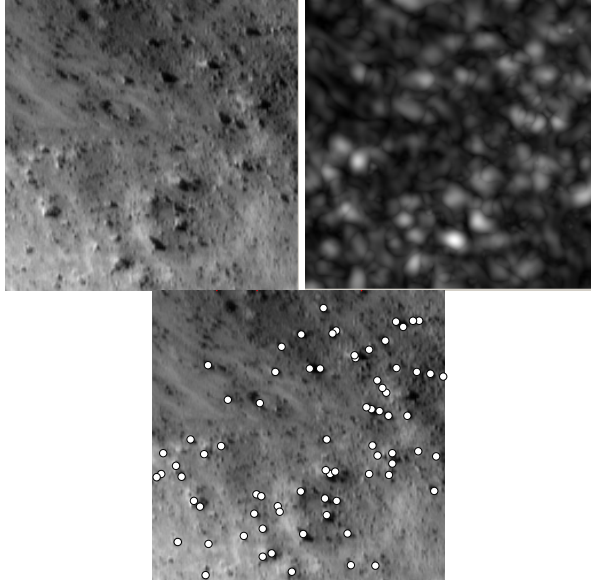


Figure 4. Gabor filter result 4 (Top: original image and Gabor filter output, Bottom: detected features).

Due to the lack of asteroid stereo image databases, a stereo pair taken by Viking Lander 1 on the surface of Mars is employed. The results show that the same features on both left/right images can be correctly matched by using the Gabor feature points as anchoring points for the correlation-based matching scheme, as shown in Figures 5-7. Being able to establish correspondence for selected feature points between left and right camera images, disparities (i.e., range) to the fiducial features can easily be computed.

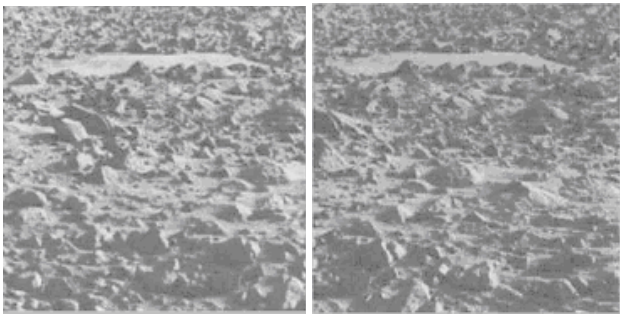


Figure 5. Original stereo images (left camera image and right camera image).

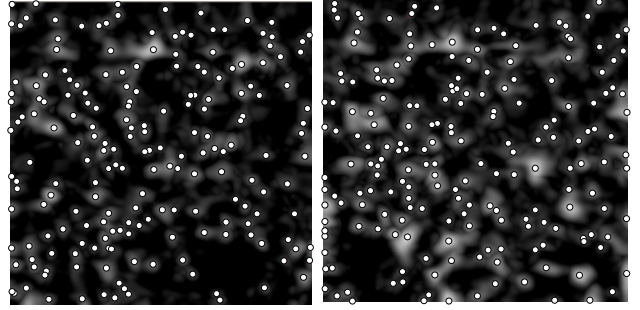


Figure 6. Gabor filter results of left camera image and right camera image.

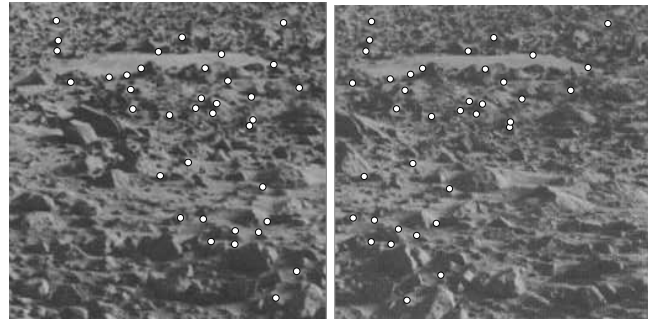


Figure 7. Matched features shown on both left and right images.

### 3. OBJECT POSITION CALCULATION

Given that two cameras are fixed on the spacecraft with their optical axes parallel. The baseline  $b$  is perpendicular to the optical axes. The spacecraft body frame can be established as shown in Figure 8. Let the baseline as  $x$ -axis,  $z$ -axis parallel to optical axis and origin in the center of baseline, and the image coordinates in left and right images be  $(x_l', y_l')$  and  $(x_r', y_r')$ , respectively. Then

$$\frac{x_l'}{f} = \frac{x + b/2}{z}, \quad \frac{x_r'}{f} = \frac{x - b/2}{z} \quad \text{and} \quad \frac{y_l'}{f} = \frac{y_r'}{f} = \frac{y}{z}$$

where  $f$  is the focal length.

From the above equations, we get

$$x = b \frac{(x_l' + x_r')/2}{x_l' - x_r'}$$

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$$y = b \frac{(y'_l + y'_r)/2}{x'_l - x'_r}, \text{ and}$$

$$z = b \frac{f}{x'_l - x'_r}.$$

If pixel resolution  $r_p$  is known, we have

$$x'_l = f * \tan(r_p x_{pl}), \quad y'_l = f * \tan(r_p y_{pl})$$

$$x'_r = f * \tan(r_p x_{pr}), \quad y'_r = f * \tan(r_p y_{pr})$$

where  $(x_{pl}, y_{pl})$  and  $(x_{pr}, y_{pr})$  are pixel coordinates in the left and right images respectively. Hence, the target position with respect to the spacecraft frame can be established.

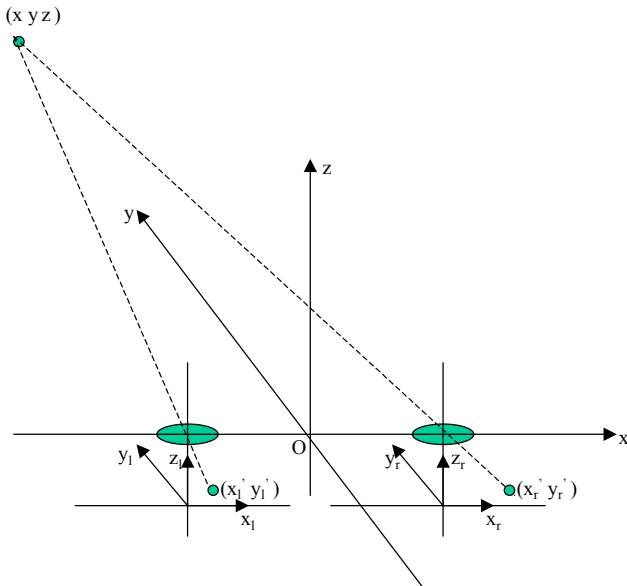


Figure 8. Coordinates of Stereo Camera System.

## 4. ASTEROID LANDING GUIDANCE

After detecting and matching features, we know the feature point pixel coordinates  $(x_{pl}, y_{pl})$  and  $(x_{pr}, y_{pr})$  in both left and right images respectively. Coordinates corresponding to Features A, B, C, D and E with respect to the spacecraft body frame can be calculated, see Figure 9.

Suppose we try to land on the predicted flat spot F, the known coordinates corresponding to Features A, B, C, D and E give a unique feature map. The geometry of the spots A, B, C, D and E can be used not only to

verify the feature matching results at different times but also to guide the spacecraft landing on the flat spot F. Actually three known spots, for instance A, B and C, can uniquely define any fixed 3D point on the asteroid surface. Using this coordinate-referencing scheme, we can determine a unique landing spot F even when there are no distinct features on the landing site.

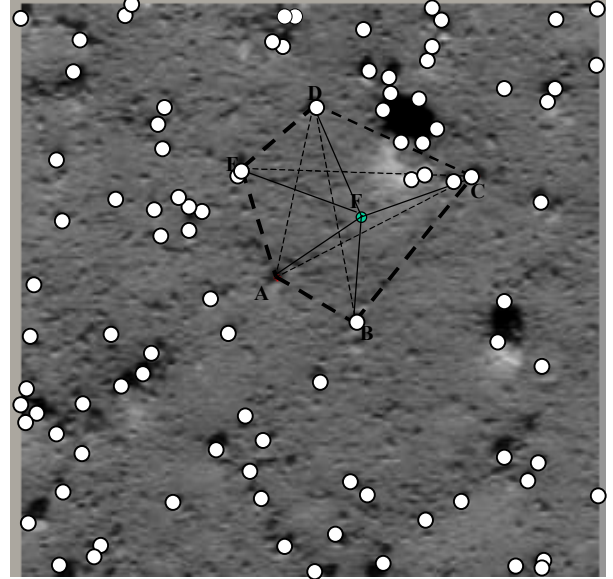


Figure 9. Feature map using stereo cameras.

Hence, autonomous target tracking and guidance signal extraction during landing operations can be accomplished as follows: at each epoch, the spacecraft captures the feature spots, verifies them with previous ones, calculates their coordinates, determines a landing spot (e.g., flat feature F) and converts F-coordinates in the image frame to the spacecraft frame.

## 5. CONCLUSIONS AND FUTURE WORK

In this paper, we demonstrated the feasibility of applying the Gabor filters and stereo cameras for autonomous target tracking and guidance signal extraction during asteroid landing operations. Although preliminary results are promising, more detailed work concerning actual implementation dealing with processing throughputs, temporal processing of electro-optical guidance signals, and image rectification for stereo cameras are needed. The



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lack of stereo image databases for asteroid landing applications also implies that further testing based on a ground-based hardware-in-the-loop simulation testbed is needed for thorough evaluation of the proposed approach.

## REFERENCES

- [1] A.E. Johnson, Y. Cheng, and L.H. Matthies, "Machine Vision for Autonomous Small Body Navigator", *IEEE Aerospace Conference Proceedings*, Vol. 7, PP.661-671, 2000.
- [2] T. Misu, T. Hashimoto and K. Ninomiya, "Optical Guidance for Autonomous Landing of Spacecraft", *IEEE Transactions on Aerospace and Electronic Systems*, Vol. 35, No. 2, PP.459-473, 1999.
- [3] C.C. Chu, M.I. Pomerantz, D. Zhu and C. Padgett, Autonomous Image-based Pointing for Planetary Flyby, *Proc. SPIE*, Vol.2466, PP.51-59, 1995.
- [4] C. Padgett and D. Zhu, "Feature-based Tracking and Recognition for Remote Sensing," *Proc. SPIE*, Vol. 2466, pp. 41-50, 1995.
- [5] R. C. Gonzalez and R. E. Woods, *Digital Image Processing*. Addison-Wesley, New York, 1992.
- [6] L. G. Brown, "A Survey of Image Registration Techniques," *Computing Surveys*, 24(4), pp. 325-376, 1992.
- [7] B. K. P. Horn, *Robot Vision*. MIT Press, Massachusetts, 1986.
- [8] C. F. Lin, *Modern Navigation, Guidance, and Control Processing*. Englewood Cliffs, Prentice-Hall, New Jersey, 1990.
- [9] C. F. Lin, *Advanced Control System Design*. Englewood Cliffs, Prentice-Hall, New Jersey, 1993.
- [10] D. Dunn, W. Higgins, and J. Wakeley, "Texture Segmentation Using 2-D Gabor Elementary Functions", *IEEE Trans. Pattern Anal. Machine Intell.*, 16(2), 1994.
- [11] R.W. Farquhar, D.W. Dunham, and J.V. McAdams, "NEAR Mission Overview and Trajectory Design", *J. Astronautical Sciences*, 43(4), PP.353-371, 1995.